

Nitrogen Removal by Orchardgrass and Smooth Bromegrass and Residual Soil Nitrate

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ABSTRACT

Nitrogen removal by cool-season grasses may aid in capturing excess N from animal confinement operations or phytoremediation. Limited information exists on the N dynamics of these grasses near the asymptote of the N response curve. The objectives of this study were to evaluate N removal, residual soil $\text{NO}_3\text{-N}$, and apparent N recovery in orchardgrass (*Dactylis glomerata* L.) and smooth bromegrass (*Bromus inermis* Leyss.) at annual N rates of 224, 448, and 672 kg ha^{-1} . Species \times harvest interactions were observed in both years, but no species \times N rate interactions occurred. Orchardgrass removed 352 and 505 kg N $\text{ha}^{-1} \text{yr}^{-1}$ at the 448 N rate compared with 207 and 371 in smooth bromegrass in 1999 and 2000, respectively. In a dry year, orchardgrass ($r^2 = 0.41$) and smooth bromegrass ($r^2 = 0.31$) exhibited linear N uptake. In a year with adequate rainfall, a quadratic relationship was observed for orchardgrass ($R^2 = 0.92$), while smooth bromegrass had linear uptake ($r^2 = 0.66$). Greater N removal was observed in orchardgrass partly because of superior fall growth, when 99 and 82 kg N ha^{-1} were removed in 1999 and 2000 at the 448 N rate compared with 23 and 15 kg N ha^{-1} in smooth bromegrass. These removal rates accounted for 28 and 16% of the seasonal total in 1999 and 2000 in orchardgrass and 11 and 4% in smooth bromegrass. Orchardgrass N removal exceeded smooth bromegrass in a three-cut system, and this difference was enhanced by utilizing the fall growth period to capture residual soil N.

NITROGEN REMOVAL of cool-season grasses is an important criterion for species selection in situations where excess soil N availability occurs. Confinement animal-production operations with land constraints for manure distribution can utilize cool-season grasses to capture large quantities of N. The resulting forage could be sold to niche markets such as the equine industry because equine can tolerate up to 10 times the level of plant tissue $\text{NO}_3\text{-N}$ concentration that is toxic to ruminants (Lewis, 1995).

Cool-season forages may also be utilized for remediation of fertilizer spill sites. Russelle et al. (2001) found 'Ineffective Agate' alfalfa (*Medicago sativa* L.) hay removed 972 kg N ha^{-1} over a 3-yr period at a fertilizer N spill site in North Dakota. Cherney et al. (2002) reported N uptake in orchardgrass and tall fescue of 139 and 157 kg N $\text{ha}^{-1} \text{yr}^{-1}$ with an average fertilizer and manure N input of 249 kg ha^{-1} from 1994 through 1997. These uptake levels are about half of those reported by Russelle et al. (2001) for alfalfa, but also represent N uptake at N rates that do not maximize yield. George et al. (1973) reported that orchardgrass and smooth bromegrass increased dry matter (DM) yields up to 672 kg N ha^{-1} .

Although cool-season grasses increase DM yield at high N rates, N recovery (kg plant N kg^{-1} N applied) generally declines as N rate increases. Ramage et al. (1958) reported fertilizer N recovery of 0.59 and 0.59 kg kg^{-1} in orchardgrass and 0.61 and 0.59 kg kg^{-1} in reed canarygrass (*Phalaris arundinacea* L.) at N rates of 56 and 448 kg N ha^{-1} , after accounting for soil N. George et al. (1973) reported maximum fertilizer N recovery of 0.49 kg kg^{-1} in a dry year, while recovery values were 0.67 in orchardgrass and 0.72 kg kg^{-1} in smooth bromegrass in a year with more normal precipitation at annual N inputs of 168 kg N ha^{-1} . These values were somewhat higher than those reported by Zemenchik and Albrecht (2002) in a three-cut harvest system under Wisconsin conditions, where apparent N recovery ranged from 0.32 to 0.50 kg kg^{-1} in orchardgrass and 0.17 to 0.44 kg kg^{-1} in smooth bromegrass at N rates ranging from 0 to 336 kg N ha^{-1} applied in split applications.

Measuring residual soil $\text{NO}_3\text{-N}$ after a fall growth cycle provides some indication of soil N available for leaching after plant growth cessation. Vetsch et al. (1999) found minimal residual soil $\text{NO}_3\text{-N}$ under reed canarygrass in November at N rates up to 449 and 393 kg ha^{-1} in the top 1.5 m of the soil profile in a wet and dry year, respectively. They concluded that reed canarygrass can serve as a sink that can assimilate excess fertilizer N up to 112 kg ha^{-1} . Kowalenko and Bittman (2000) found 1, 23, and 10 mg N kg^{-1} in the top 60 cm of the soil profile in the fall after fourth cut in three consecutive years in plots of predominately orchardgrass that received 200 kg N ha^{-1} in early spring followed by 100 kg N ha^{-1} after the first and second cuttings. Limited residual soil $\text{NO}_3\text{-N}$ data are available in the literature at N rates that exceed annual applications greater than 400 kg N ha^{-1} in orchardgrass and smooth bromegrass. The objectives of this study were to measure N removal, residual soil $\text{NO}_3\text{-N}$, and apparent N recovery of mono-specific cultures of orchardgrass and smooth bromegrass at optimum and very high N rates.

MATERIALS AND METHODS

A 2-yr field study was established in the fall of 1998 on a Quakertown silt loam (fine-loamy, mixed, mesic Typic Hapludults) at the Rutgers University Snyder Research and Extension Farm near Pittstown, NJ (40° 30' N, 75° 00' W). 'Pennlate' orchardgrass and 'Saratoga' smooth bromegrass were seeded as main plots at 13 kg seed ha^{-1} with an oat (*Avena sativa* L.) cover crop (54 kg seed ha^{-1}) on 11 September. A commercial grain drill was used in 61- \times 17-m plots in a randomized complete block with a split-plot arrangement of treatments and four replications.

Main plots were forage species. Subplots consisted of three N rates, 224, 448, and 672 kg N $\text{ha}^{-1} \text{yr}^{-1}$. These rates were achieved by supplying either 112, 224, or 336 kg N ha^{-1} in the spring at green-up followed by 56, 112, or 168 kg N ha^{-1} ,

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respectively, after the first two harvests each year. All N was applied as ammonium nitrate with a drop spreader.

Before seeding, lime was broadcast and incorporated to bring soil pH to 6.2. Approximately 3350 kg ha⁻¹ lime was added in the spring of 2000 to maintain soil pH. Soil test results indicated that available P and exchangeable K were 230 and 260 kg ha⁻¹ before establishment. Consequently, 280 kg ha⁻¹ K was broadcast and incorporated before seeding. Thereafter, fertilizer was added to maintain soil P and K above 80 and 310 kg ha⁻¹. Dicamba (3,6-di-chloro-2-methoxybenzoic acid) was applied at 0.28 kg a.i. ha⁻¹ in the spring of 1999 to both species and 0.56 kg a.i. ha⁻¹ to smooth brome grass in the spring of 2000.

Commercial equipment was used to harvest orchardgrass (11 May, 22 June, and 31 August) and smooth brome grass (26 May, 20 July, and 24 September) three times for hay in 1999 and 2000 (5 May, 22 June, and 21 August for orchardgrass, and 26 May, 11 July, and 5 September for smooth brome grass). Singer (2002a) provides more detail about growth stage of plants at harvest and harvest procedures. Immediately before mowing, forage samples were collected from four 0.25-m² quadrats in each subplot by clipping to a 6-cm height. Within each growth cycle, forage samples were generally collected on a 5- to 10-d sampling schedule using a similar sampling protocol. Forage samples were also collected in a similar procedure after a killing frost in the fall of 1999 and 2000 (Harvest 4) to measure N removal without additional N input after third harvest.

All samples were placed in a forced-air oven at 50°C to determine moisture concentration. After all samples reached a constant weight (within 96 h), they were weighed and then ground through a Wiley mill to pass a 1-mm mesh screen. Total N was determined by a modified Kjeldahl procedure (Kjeltech Auto 1030 Analyzer, Tecator, Herndon, VA). Nitrogen removal was calculated as the product of forage dry matter yield and N concentration. The drying rate used in this study (50°C) may not have ceased respiration fast enough to eliminate dry matter losses that could have unequally affected DM data and subsequent N removal.

Apparent N recovery was limited to N rates above 224 kg N ha⁻¹ year⁻¹ because a 0 N treatment was not included in our study. Consequently, apparent N recovery was calculated as the quantity of N removed in the herbage for different fertilizer N increments divided by the difference in N applied (e.g., N removal₄₄₈ - N removal_{224/448} - 224).

Composite residual soil NO₃-N samples were obtained the day after each harvest by randomly collecting four soil cores per subplot from the 0- to 0.3-m and the 0.3- to 0.6-m soil depths. Samples were not collected after third harvest of smooth brome grass in 1999. Residual soil NO₃-N samples were collected at the same time forage samples were collected in the fall after a killing frost. Samples were dried immediately in a forced-air oven at 45°C and analyzed for NO₃-N colorimetrically with an autoanalyzer (Alpkem Corp., Clackamas OR). Because limited long-term weather data were not available at the test site, the closest weather station (11 km) with long-term data was used for average air temperature and precipitation.

Statistical significance of treatment effects was assessed using analysis of variance procedures (Lorenzen and Anderson, 1993). The Bartlett test on the full model indicated that error terms for most data sets were not homogeneous, so a separate analysis is presented for each year. The effect of harvest dates within years was analyzed using a split plot in time univariate analysis (Littell et al., 1997). Statistical analyses of treatment and harvest comparisons were conducted by the General Linear Models (GLM) procedure of the Statistical Analysis System (SAS, 2000). Regression models were fitted by the REG

procedure of SAS. Mean comparisons were made using an *F*-protected least significant difference test (Steel et al., 1997). All tests of significance were made at the *P* = 0.05 level unless otherwise specified.

RESULTS AND DISCUSSION

Nitrogen Removal

Below average precipitation from May through mid-August and above average air temperatures from May through September occurred in 1999 (Table 1). In contrast, the 2000 growing season was characterized by average precipitation, except for July and August, when precipitation was 26% below and 31% above average.

Differences in N removal among N rates in 1999 were limited to Harvest 1 in orchardgrass and Harvests 1 and 3 in smooth brome grass (Fig. 1). At Harvest 1, orchardgrass at the 448 and 672 kg N ha⁻¹ rates removed 16 and 22% more N than the 224 rate. The 672 N rate in smooth brome grass at Harvest 1 removed 31% more N than the average of the 224 and 448 N rates. The 448 and 672 N rates in smooth brome grass at Harvest 3 had 17 and 14% more N removal than the 224 N rate.

In 2000, with adequate precipitation, differences in N removal among N rates in orchardgrass occurred at all three harvests. Orchardgrass N removal increased up to the 448 N rate at all harvests. At first harvest, the average removal of the 448 and 672 N rates was 177 compared with 131 kg N ha⁻¹ at the 224 N rate. At second harvest, the 448 and 672 N rates removed on average 25% more N compared with the 224 N rate. Average N removal per harvest for the 448 and 672 N rates was 112 compared with 75 kg N ha⁻¹ at the 224 N rate. Smooth brome grass N removal was similar at the 448 and 672 N rates in 2000 at first harvest. The 224 N rate removed 14% less N than the average removal of the 448 and 672 N rates at Harvest 1. Incremental increases were observed at Harvest 2, when the 672 N rate removed 24% more N than the 448 N rate and the 448 N rate removed 51% more N than the 224 N rate. Nitrogen removal was similar between the 448 and 672 N rates at Harvest 3 in smooth brome grass, and averaged 39% greater than the 224 N rate.

Our N removal values, except for smooth brome grass in 2000 at the high N rate, exceeded levels of George et al. (1973). They reported uptake in orchardgrass and smooth brome grass of 238 and 168 kg ha⁻¹ in a dry year and 374 and 431 kg ha⁻¹ in a year with average rainfall at annual inputs of 672 kg N ha⁻¹. The higher N removal

Table 1. Mean monthly air temperature and precipitation in 1999 and 2000 near Pittstown, NJ.

Month	Air temperature			Precipitation		
	1999	2000	Average†	1999	2000	Average
	°C			mm		
May	16.2	16.2	15.0	59	119	117
June	20.8	20.6	20.2	20	98	107
July	24.2	21.3	23.0	31	92	124
August	22.3	20.8	22.2	118	130	99
September	19.2	17.1	17.9	346	105	99

† Averages are of previous 30 yr measured at a weather station 11 km from experimental site.

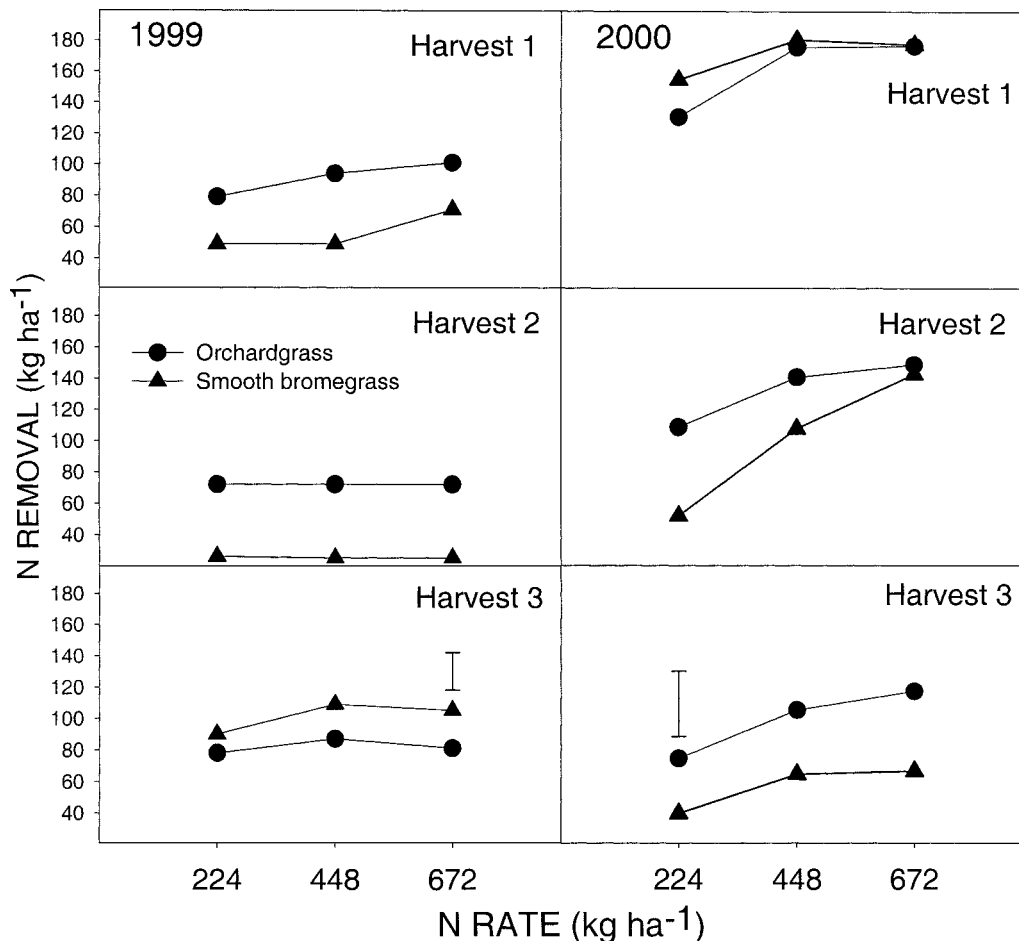


Fig. 1. Nitrogen removal at fertilization rates of 224, 448, and 672 kg N ha⁻¹ year⁻¹ in orchardgrass and smooth brome grass in a three-harvest system in 1999 and 2000, near Pittstown, NJ. Vertical bars are the LSD at the 0.05 significance level and compare N rate means for the same species and the same or different harvests.

in our experiment cannot be explained because of higher tiller densities. George et al. (1973) reported tiller densities of 827 and 740 tillers m⁻² for orchardgrass and smooth brome grass in the summer following two harvest seasons. Singer (2002b) reported tiller densities of 516 and 276 tillers m⁻² in orchardgrass and smooth brome grass after six harvests (2 yr) at a similar N rate.

Differences in N removal were observed at specific harvests, but N removal also varied temporally within growth cycles. Before first harvest in 1999, no difference at day of year (DOY) 118 was observed among N rates in orchardgrass (Fig. 2). At DOY 125, the 448 and 672 N rate curves diverged from the 224 N rate curve, and maintained greater N removal until harvest at DOY 131. The response pattern in smooth brome grass during the first growth cycle in 1999 cannot be adequately described because of limited sampling. Nevertheless, separation of N rates occurred at DOY 146, when the 672 N rate had greater N removal than the 224 or 448 N rates. Orchardgrass at the 224 N rate at DOY 156 during the second growth cycle accumulated 62 compared with 54 and 39 kg N ha⁻¹ at the 448 and 672 N rates. Fertilizer injury was observed at the 448 and 672 N rates (Singer, 2002b), which temporarily reduced N removal during the second growth cycle and resulted in similar N removal among N rates at second harvest at DOY 174.

Differences in N removal in smooth brome grass during the second growth cycle were not observed in 1999. The 672 N rate in orchardgrass at the first sampling time (DOY 183) during the third growth cycle had greater N removal than the 224 N rate. However, differences were not detected among N rates during the remainder of the third growth cycle in 1999. Timely rains between the fifth and final sampling time in orchardgrass increased N removal dramatically at rates of 3.5, 4.6, and 4.1 kg N ha⁻¹ d⁻¹ at the 224, 448, and 672 N rates. Smooth brome grass N removal increased markedly after the third sampling time at DOY 230 until harvest at DOY 267 at rates of 2.0, 2.5, and 2.4 kg N ha⁻¹ day⁻¹ at the 224, 448, and 672 N rates. The higher removal rates at the 448 and 672 rates in smooth brome grass increased N removal at Harvest 3 compared with the 224 N rate.

More pronounced separation of N treatments during all growth cycles was observed in 2000 in both species. Nitrogen rates in orchardgrass had similar to small differences in N removal during the first growth cycle until approximately 20 d after N application. After this time the 448 and 672 N rates maintained high rates of N removal while the 224 N rate experienced lower N removal. Although no fertilizer injury was observed in 2000, orchardgrass at the 224 N rate had higher N removal than the 448 and 672 N rates from DOY 137 to

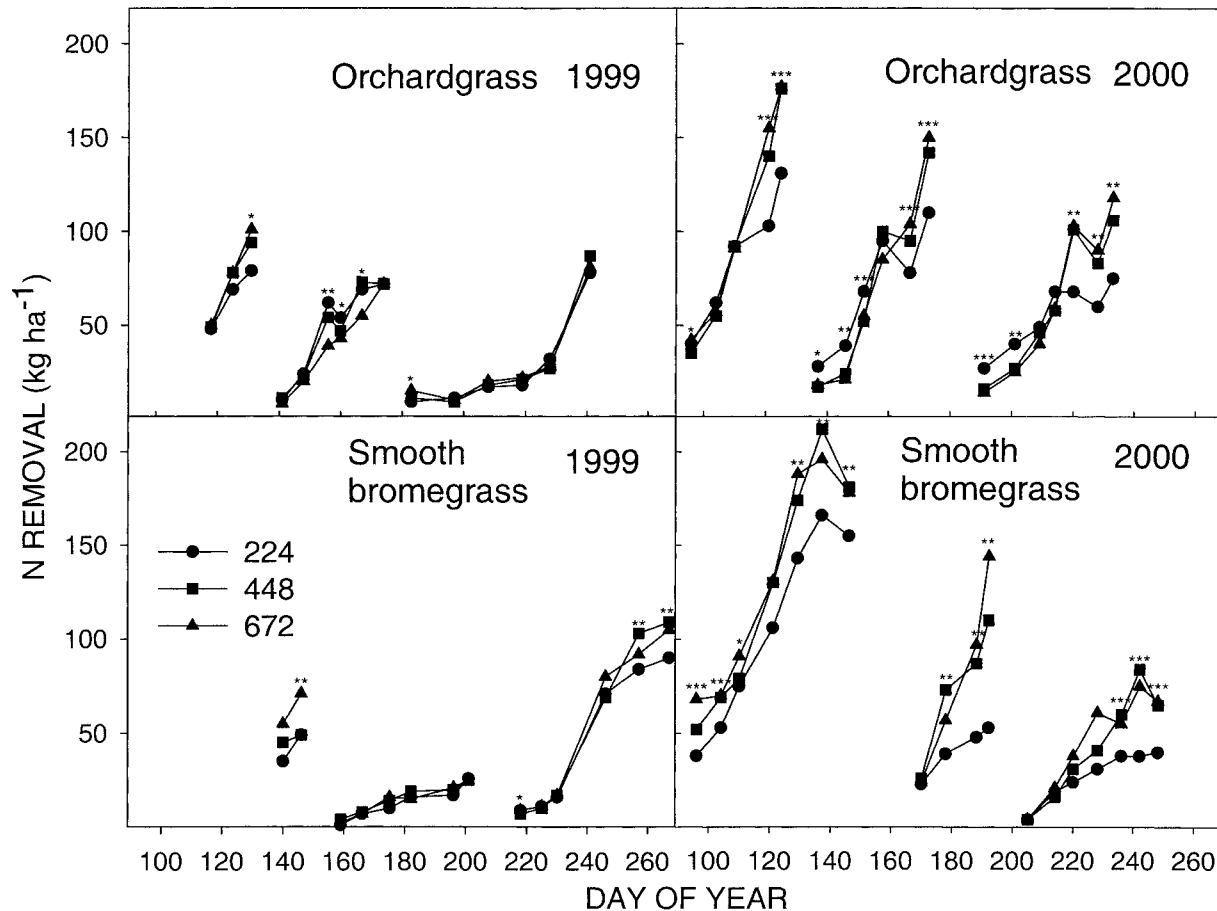


Fig. 2. Nitrogen removal within three growth cycles in orchardgrass and smooth brome grass at 224, 448, and 672 kg N ha⁻¹ yr⁻¹ in a three-harvest system in 1999 and 2000, near Pittstown, NJ. *, **, and *** indicate significance at 0.1, 0.05, and 0.01.

152 during the second growth cycle and DOY 191 to 201 during the third growth cycle.

Nitrogen removal varied among N rates in smooth brome grass in 2000. Separation of N rates was observed in less than 15 d after N application during the first smooth brome grass growth cycle. Smooth brome grass N removal declined from DOY 137 to 146, which is consistent with Hall (1998), who reported decreasing N status in smooth brome grass as harvest interval increased. We were unable to harvest the first cutting of smooth brome grass in 2000 until R3 (Moore et al., 1991) because of adverse weather conditions. During the second growth cycle, differences among N rates did not appear in smooth brome grass until DOY 178, and persisted until harvest on DOY 192. The 672 N rate did not remove the most N until DOY 188, 41 d after N application and only 4 d before second harvest. Separation of N rates during the third growth cycle did not occur until 43 d after second harvest and 12 d before third harvest.

Seasonal N removal was highly significant for species and N rate, but no significant interactions were observed in either year between species and N rate treatments. Although significant species \times harvest interactions were observed in both years (Fig. 1), seasonal N removal includes the fall growth period and provides important information about potential removal of these species

regardless of harvest-to-harvest variation. Both species had linear N removal in 1999 (Fig. 3). In 2000, a quadratic model provided the best fit to the seasonal N removal data for orchardgrass, while smooth brome grass exhibited linear N removal. Orchardgrass removed 352 and 505 kg N ha⁻¹ yr⁻¹ at the 448 N rate compared with 207 and 371 in smooth brome grass in 1999 and 2000, respectively. In both years, the 448 and 672 N rates in orchardgrass removed similar levels of N and were both greater than the 224 rate. In contrast, differences were limited to the 224 and 672 N rates in 1999 in smooth brome grass. In 2000, the 448 and 672 N rates removed similar levels of N and were both greater than the 224 rate.

Residual Soil NO₃-N

Residual soil NO₃-N in orchardgrass and smooth brome grass in 1999 at the 224 N rate at Harvest 4 was 1 and 4 and 6 and 7 mg kg⁻¹ from the 0- to 0.3- and 0.3- to 0.6-m soil depths (Fig. 4). Residual soil NO₃-N peaked in orchardgrass in 1999 at the 672 N rate from the 0- to 0.3-m soil layer after second harvest because of dry conditions that limited N removal during the second growth cycle. Conversely, above average precipitation during the fourth growth cycle leached soil NO₃-N to the second soil depth in 1999. Residual soil

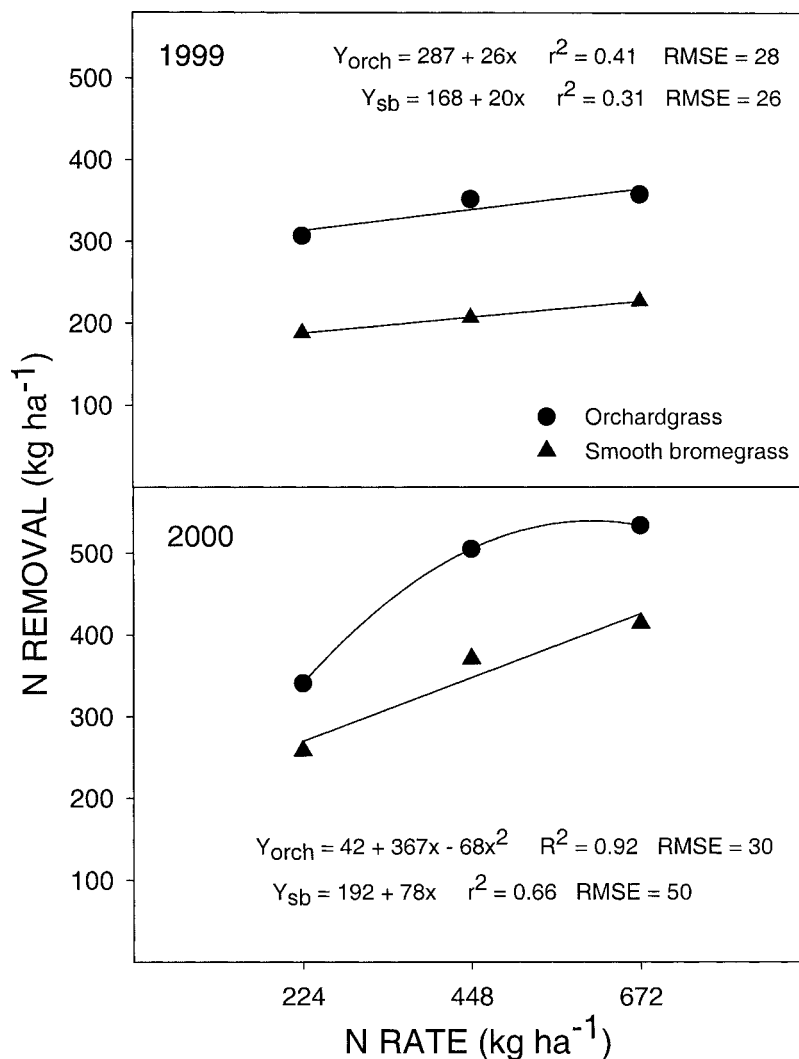


Fig. 3. Total nitrogen removal in orchardgrass and smooth bromegrass at 224, 448, and 672 kg N ha⁻¹ yr⁻¹ in 1999 and 2000, near Pittstown, NJ.

NO₃-N in orchardgrass at the 672 N rate at Depth 2 was 47 mg kg⁻¹ after Harvest 4. During the fourth growth cycle, orchardgrass removed 77, 99, and 104 kg N ha⁻¹ at the 224, 448, and 672 N rates. Differences between the 0- to 0.3- and 0.3- to 0.6-m soil depths in orchardgrass were most likely due to the high N removal that occurred from the 0- to 0.3-m depth during the fourth growth cycle. No difference between depths in the 672 N rate was observed in smooth bromegrass, where the 224, 448, and 672 N rates removed 23, 23, and 27 kg N ha⁻¹. The duration of the fourth growth cycle in orchardgrass lasted 47 d compared with 23 d in smooth bromegrass.

In 2000, residual soil NO₃-N did not accumulate to levels greater than 7 mg kg⁻¹ at the 224 or 448 N rates for either species in the top 0.6-m soil depth after Harvest 4. At the 672 N rate in orchardgrass and smooth bromegrass at the same sampling time, 40 and 27 mg kg⁻¹ soil NO₃-N were found in the top 0.6 m of the soil profile. The fourth growth cycle in orchardgrass lasted 80 d and 25, 82, and 89 kg N ha⁻¹ were removed at the 224, 448, and 672 N rates. In contrast, smooth bromegrass removed 10, 15, and 26 kg N ha⁻¹ during the fourth

growth cycle (71 d) at the 224, 448, and 672 N rates. Smooth bromegrass had similar or lower residual soil nitrate levels at the different N rates than orchardgrass, yet had less seasonal N removal. This difference may be partially explained by N incorporated in root mass. Power (1986) reported that smooth bromegrass root N uptake at a fertilizer rate of 225 kg N ha⁻¹ yr⁻¹ in a single-cut system was 184 and 177 kg N ha⁻¹ in October and August of the first 2 yr of a long-term experiment. We did not measure root N, but growth habit differences between orchardgrass and smooth bromegrass may alter root N sink potential.

Apparent Nitrogen Recovery

An inverse relationship was observed between N input and apparent N recovery. Nitrogen recoveries were low in 1999 and ranged from 0.20 kg kg⁻¹ in orchardgrass from the 224 to 448 N increment and 0.03 kg kg⁻¹ from the 448 to the 672 N increment. In smooth bromegrass in 1999, apparent N recoveries were 0.08 kg kg⁻¹ and 0.09 for the same increments. In 2000, apparent N recoveries in orchardgrass were 0.73 and 0.13 kg kg⁻¹ and

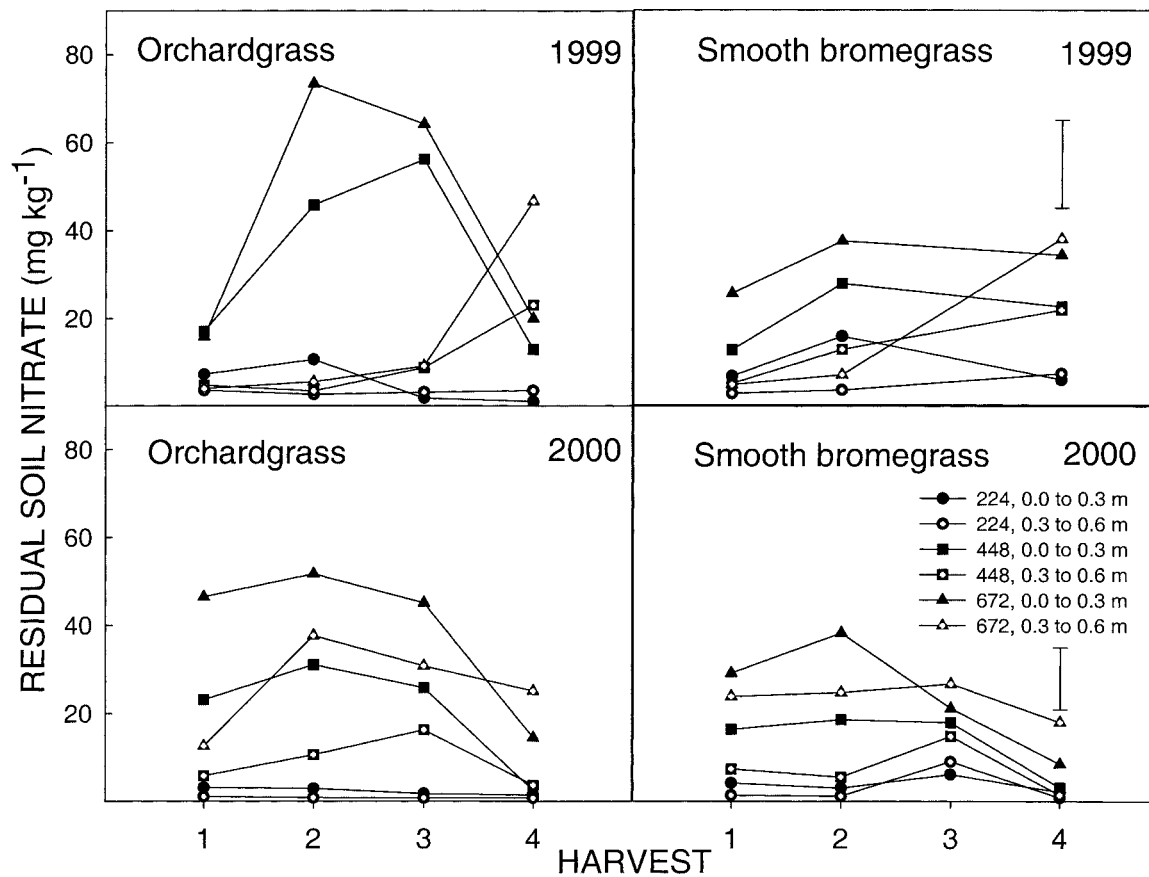


Fig. 4. Residual soil $\text{NO}_3\text{-N}$ in orchardgrass and smooth bromegrass at 224, 448, and 672 $\text{kg N ha}^{-1} \text{yr}^{-1}$ from the 0- to 0.3- and 0.3- to 0.6-m soil depths at four harvests in 1999 and 2000, near Pittstown, NJ. Harvest 4 corresponds to sampling after a killing frost. Vertical bars identify LSD to separate soil depth means for the same N rate, species, harvest, and year at the 0.05 significance level.

0.50 and 0.19 kg kg^{-1} in smooth bromegrass. George et al. (1973) suggested that established sod-forming species such as smooth bromegrass may be more efficient at recovering N than bunchgrasses such as orchardgrass. We found that orchardgrass recovered more N in forage biomass than smooth bromegrass from the 224 to the 448 N rate in both years, but smooth bromegrass recovered more N from the 448 to the 672 N rate increment. A zero N treatment was not included in this study. Consequently, we could not subtract the soil N contribution from total N removal. Zemenchik and Albrecht (2002) found that the soil N contribution, averaged across years, was similar in Plano and Rozetta silt loams and contributed 78 and 65 kg N ha^{-1} in smooth bromegrass and orchardgrass. Capturing N above ground in the forage until a killing frost reduced residual soil $\text{NO}_3\text{-N}$ values to comparatively low levels at the 224 and 448 N rates in 1999 and at all N rates in 2000. However, it is unclear how much of the N removed in the fall was derived from fertilizer N compared with soil N. Stout and Jung (1992) applied N in late July to orchardgrass and only realized a 15% N recovery during the fall growth period. They concluded that differences in plant morphology may explain differences in fertilizer N uptake in the spring compared with the fall growth periods. Unaccounted for N in our study may have leached lower than 0.6 m in the soil profile (Vetsch et al., 1999), may

have been sequestered by roots, denitrified, or lost through NH_3 volatilization.

CONCLUSIONS

Nitrogen uptake varied by year because of contrasting environmental conditions. In both years, species \times harvest interactions were observed but no species \times N rate interactions occurred. Separation of N rates within growth cycles was delayed when N responses were observed at specific harvests. Consequently, sufficient harvest intervals are necessary to obtain the maximum benefit for N removal. Utilizing the fall growth period to capture N favors orchardgrass because of superior fall growth compared with smooth bromegrass. Orchardgrass captured more total N than smooth bromegrass and demonstrated superior potential for N removal in this harvest system.

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